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Low Temperature MOS Device Modeling

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ABSTRACT: The state of the art in self consistent numerical low temperature MOS modeling is reviewed. The physical assumptions which are required to describe carrier transport at low ambient temperatures are discussed. Particular emphasis is put on the models for space charge (impurity freeze out), carrier mobility (temperature dependence of scattering mechanisms at a semiconductor-insulator interface) and carrier generation-recombination (impact ionization). The differences with regard to the numerical methods required for the solution of low temperature models compared to room temperature models are explained. Typical results obtained with the simulator MINIMOS 4 are presented. These include comparisons of hot-electron phenomena like energy relaxation and avalanche breakdown at 77K and 300K ambient temperature.

INTRODUCTION

Device Modeling based on the self-consistent solution of fundamental semiconductor equations dates back to the famous work of Gummel in 1964 [2]. However, the first application of this rigorous style of modeling for problems at low ambient temperature (usually liquid nitrogen temperature) has first been carried out by Gaensslen about fifteen years later in 1979 [3]. The main reason for this delay cannot only be seen in the lesser demands for low temperature simulation but primarily in considerably increased difficulties regarding physical assumptions and implementation for a numerical solution.

PHYSICAL ASPECTS

In order to account properly for carrier transport at low temperature one major additional phenomenon has to be taken into account in contrast to room temperature applications. This is the partial ionization of the impurity concentration dependent on the position of the Fermi level. Of lesser but not negligible importance is degeneracy in the MOS inversion layer which requires at least a correction of the Boltzmann expressions for the free carrier concentrations where the Fermi level may enter the conduction or valence band. The models for carrier mobilities and carrier generation-recombination have to be appropriately adapted from the quite established models available for room temperature applications. As additional minor effect neutral impurity scattering has to be considered to remain consistent with partial ionization. The status of knowledge about the temperature dependence of all these physical parameters will be reviewed.

NUMERICAL ASPECTS

Almost none of the many device simulation programs which have proven their usefulness for room temperature simulations can be directly applied to low temperature applications. The primary reason for this is the scaling of carrier concentrations with all thereby induced consequences. Briefly sketched: De Mari recommended in an early paper [1] to scale the intrinsic carrier concentration to unity, which contributes to change the basic semiconductor equations into a dimensionless form very convenient for computer implementation. Due to the fact that the intrinsic carrier concentration at liquid nitrogen temperature is in the order of $10^{-20}cm^{-3}$, it is obviously not usable for scaling in this case, since for instance an impurity concentration of $10^{20}cm^{-3}$ would then be scaled to 10^{40}. To scale the maximum impurity concentration to unity as recommended in the elaborate mathematical book of Markowich [4] is also not feasible, since the scaled intrinsic concentration would be in the order of 10^{-40}. A way out of this dilemma will be presented.

REFERENCES

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